Stewart Platform Robotic Wrist

Gustavo Rivera Soto, Alejandro Porras Diaz, Leo Critchfield, Tom Whiteley
University of Rochester, Hajim School of Engineering and Applied Sciences
Department of Mechanical Engineering

Problem Statement

Parallel jaw grippers for the Sawyer Robotic Manipulator lack the degrees of freedom to replicate the motion and flexibility of a human wrist. This project focuses on combining a 6 degree of freedom (DOF) wrist joint using a "Stewart Strut" platform and a parallel gripper. The project is carried out in conjunction with an ECE design team for the electronic and programming aspects of the device.

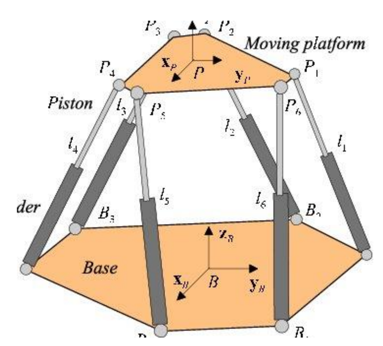

Figure 1. Stewart Strut Platform

Figure 2. Sawyer Robot with existing parallel gripper

Requirements and Specifications

Requirements:

- Motion plate must exhibit motion in 6 degrees of freedom.
- Mechanical system must interface with the Rethink Sawyer Robot .
- Design must allow power and signal wires to pass through uninhibited.
- Grippers must be able to grasp and hold a tennis ball.
- Must enclose MCU, motor controllers, voltage regulators and interfaces.
- The gripper must be interchangeable on the motion plate.

Specifications:

- Minimum translation (x,y,z) in the base frame of 3 centimeters.
- Minimum rotation (rx,ry) in the base frame of 30°
- Minimum rotation about the z axis (rz) in the base frame of 15°
- Maximum device height in the base frame (cylinder envelope excluding the gripper assembly) of 15 centimeters.
- Maximum device diameter of 8 centimeters.
- A minimum payload of 0.5 kilograms to be held securely by the gripper.
- A maximum device mass (platform and gripper) of 2 kilograms.

Concept Development

A structural analysis was completed on 4 hexapod configurations (6-6, 3-6, 6-3, 3-3) to determine the most suitable design. Based on its forces and manufacturability, Type 6-6 was chosen.

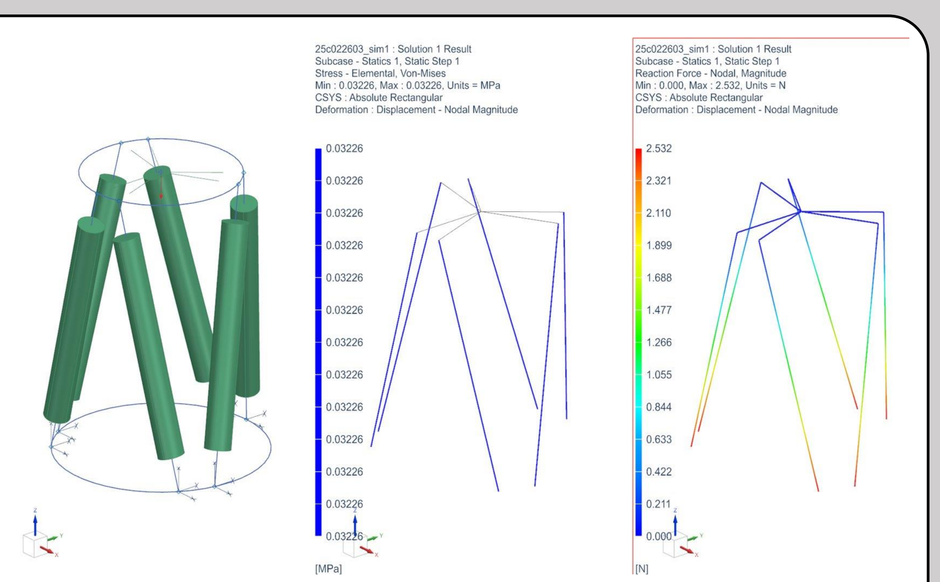

Figure 3. Structural analysis on NX of type 6-6 hexapod set up.

Linear actuators were chosen to control the platform and CAD models were developed for three candidates. Based on its ability to meet specifications, limit interference, and provide position feedback the Actuonix L12 Actuator was chosen.

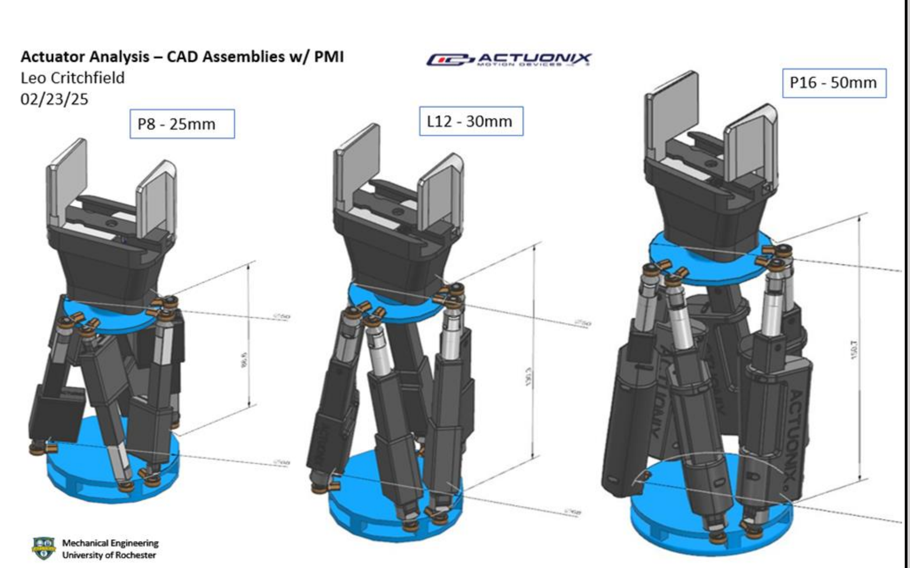

Figure 4. Actuator Assemblies used for comparison

Final Design

Figure 5. Gripper exploded view

Design attributes:

- Modular removable 3D printed gripper
- Separated Sawyer and platform base plates
- Universal joints (fixed on base and free to rotate about top plate using with bushings and shoulder bolts)
- Custom actuator connectors (threaded top inserts and bottom connecting blocks)
- Base plate U-Joints risen with dowel pins and spacers for PCB clearance

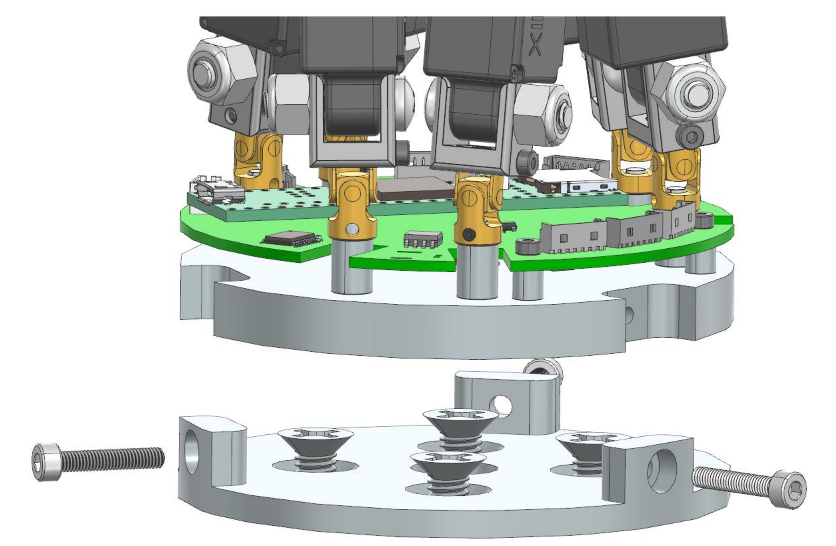

Figure 6. Platform Base exploded view

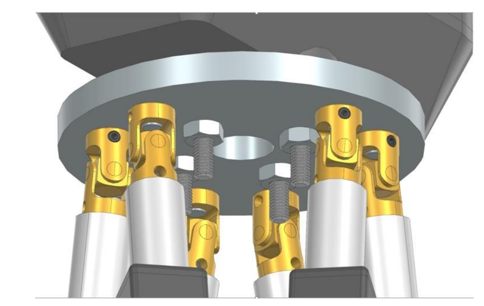

Figure 7. Top plate gripper connection

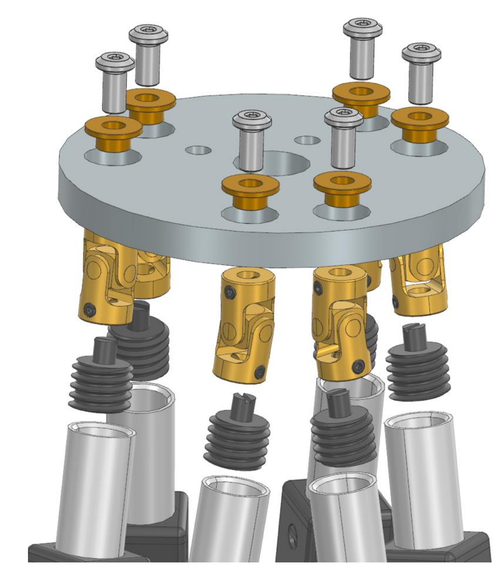

Figure 8. Top plate exploded view

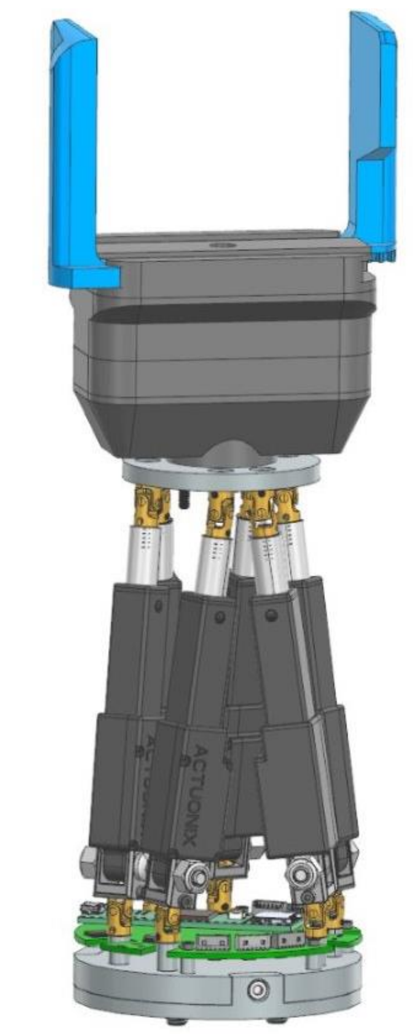

Figure 9. Complete Device CAD

Analysis

A dynamic model and fatigue analysis were created to evaluate operation of the device before construction. The dynamic simulation modeled worst-case forces acting on the platform and actuators at various orientations. Using harmonic movement, the maximum force in a single actuator reached 2.5 N during nominal movement and 14N with lockup— both within the L12 actuators' 22 N capacity. Using the maximum force a single U-Joint pin would experience; the fatigue analysis satisfied the infinite life criterion for both the Soderberg and Modified Goodman methods ensuring no number of cycles would cause failure.

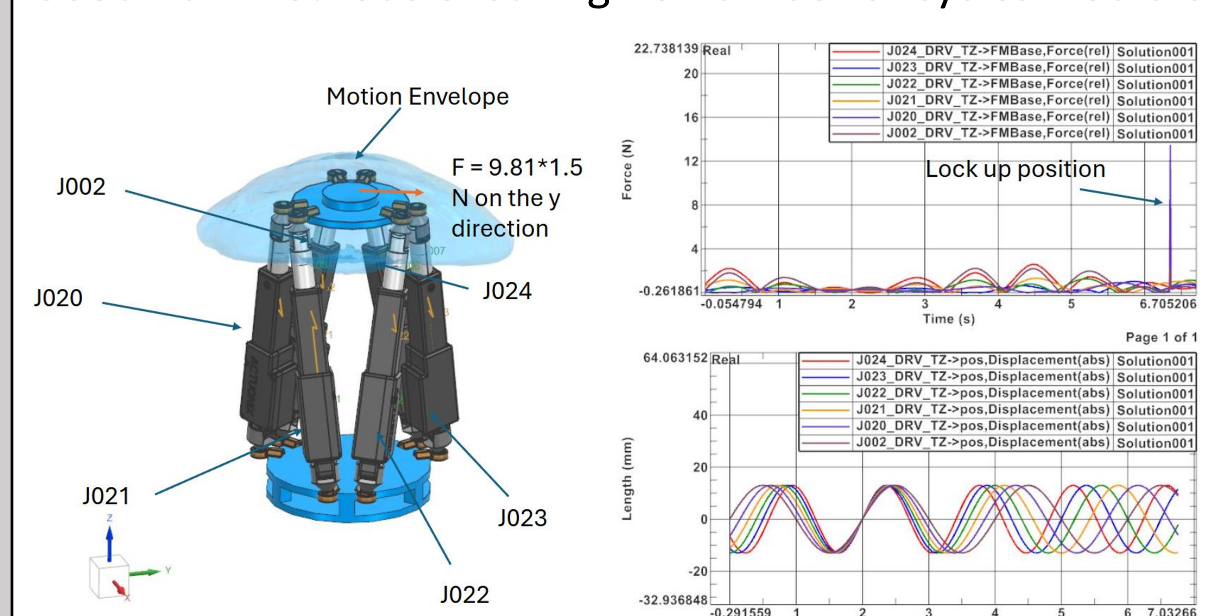

Figure 10. Mechanical simulation of the Stewart platform with lockup

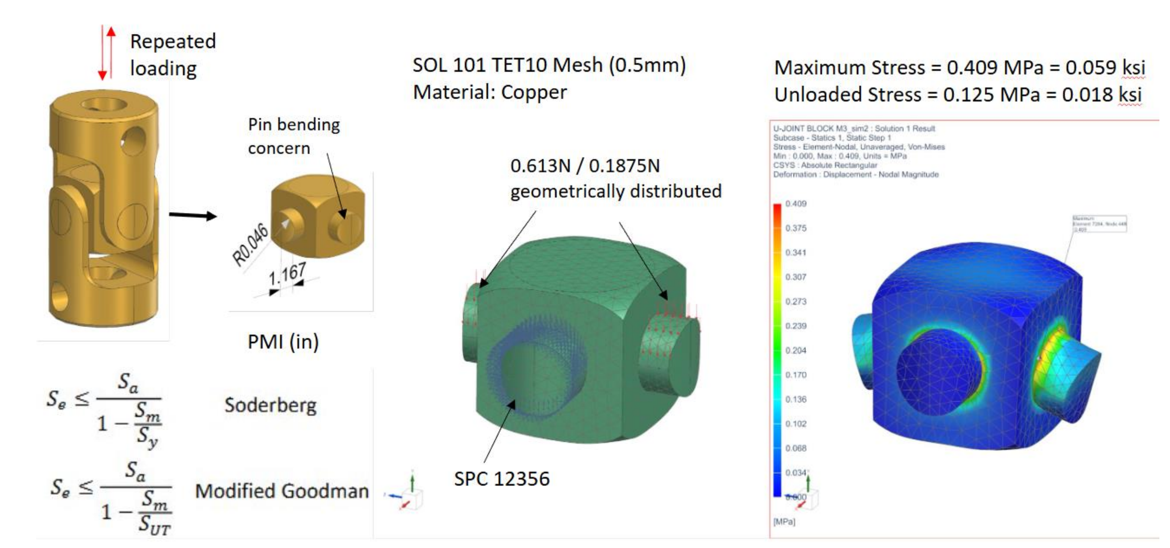

Figure 11. Fatigue analysis of the U-Joint block pins

Manufacturing

To efficiently construct the Stewart strut, the team divided machining tasks among smaller groups, with each member responsible for a specific component: one programmed HAAS CNC code in Siemens NX for the Sawyer Plate, another did the same for the Connecting Block, a third used a manual lathe to produce precision Connecting Pins, and the last handled the Top and Bottom Plates using both CNC ProtoTrak and manual milling. Simultaneously, the team developed a mechanical gripper through iterative 3D printing, starting with an initial prototype for testing and refining it into a more reliable and optimized second version, enabling rapid development alongside the machining of the core structure.

HAAS CNC

Figure 12. Sawyer Interference Plate and Connection Block

CNC Proto Trak

Figure 13. Bottom Base and Top Plates

Testing

The Quantum X FaroArm® was used to scan the Stewart Strut assembly, measuring displacements relative to the base to verify range of motion and system accuracy. The setup involved calibrating both base and top plates and actuating the platform to its extreme positions to capture maximum translation, tilt, and twist. Testing confirmed that all design specifications were met, including the expected Z-translation limit of three centimeters due to actuator stroke constraints.

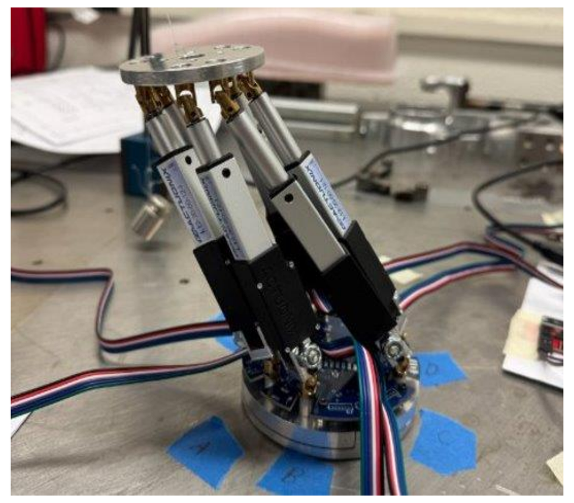

Figure 14. Max Translation Testing

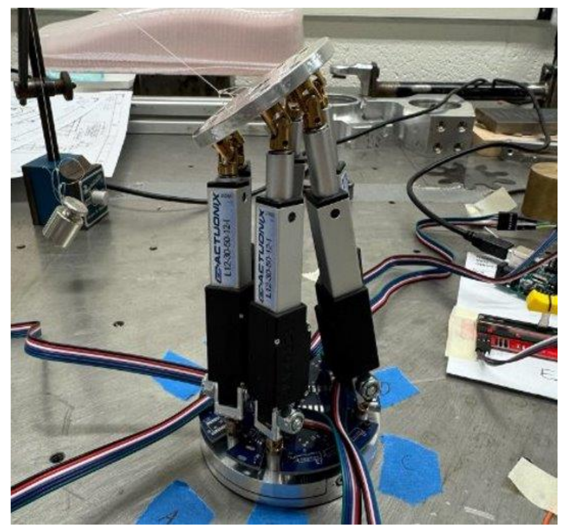

Figure 15. Max Tip/Tilt testing

Figure 16. Complete Physical Device

Specification	Required	Tested	Pass/Fail
Minimum translation in the x, y, and z coordinates in the base frame.	3 cm	Z: 2.93 X: 4.3 Y: 4.1	PASS
Minimum rotation about x and y coordinate axis in the base frame.	30°	X: 33.1° Y: 38°	PASS
Minimum rotation about the z coordinate axis in the base frame.	15°	60.8°	PASS
Maximum device height.	15 cm	14.94 cm	PASS
Maximum device diameter.	8 cm	8 cm	PASS
Minimum payload to be held securely by the gripper.	0.5 kg	0.8 kg	PASS
Maximum mass of the whole assembly	2 kg	0.674 kg	PASS

Table 1. Test data obtained against specifications values

Future Work

For the design, the Sawyer plate and bottom plate could be improved by refining the connections and constraints between them. The bottom U-Joints connections could be improved by sinking the PCB into the base plate. For manufacturing, fabricating custom universal joints could help reduce mechanical slack. The sawyer and bottom plate could be machined as an assembly for improved alignment.

Acknowledgements

The team would like to thank our sponsor Professor Thomas Howard, as well as Professor Muir, Chris Pratt, Jim Alkins, Bill Mildenberger, Alex Prideaux and Samantha Kriegsman for all their support and guidance throughout the project.